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THE ORGANIZATION OF INTERRELATED INDIVIDUAL PROGRESS AND ABILITY LEVEL COURSES IN MATHEMATICS AT GARBER HIGH SCHOOL--SYSTEM ANALYSIS AND SIMULATION.

BY- BRATTEN, JACK E.
SYSTEM DEVELOPMENT CORP., SANTA MONICA, CALIF.

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A MODEL OF THE MATHEMATICS DEPARTMENT AT THE GARBER HIGH SCHOOL AS ESSEXVILLE, MICHIGAN, AS A SYSTEM FOR PROCESSING STUDENTS WAS DESCRIBED IN THE LAST OF A SERIES OF THREE REPORTS. THE RESULTS OBTAINED THROUGH SIMULATING THE SYSTEM ON A COMPUTER WERE ALSO REPORTED. A FEATURE OF THE PLAN WAS NOTED TO BE ITS FLEXIBILITY IN PROVIDING A UNIQUE PROGRAM OF COURSES TO MEET THE VARIED ABILITIES AND INTERESTS OF INDIVIDUAL STUDENTS. DESCRIPTIONS WERE GIVEN OF (1) A MODEL OF COURSES IN MATHEMATICS SHOWING THE INTERRELATIONSHIPS AMONG 29 COURSES OFFERED BY THE DEPARTMENT AND THE PATHWAYS BY WHICH THE STUDENTS MAY PROCEED, (2) RESULTS OF A COMPUTER SIMULATION OF STUDENT BEHAVIOR AS THEY ARE PROCESSED AND TO PREDICT THE USE TO BE MADE OF THE VARIOUS COURSES WHEN THE DEPARTMENT BECOMES FULLY OPERATIONAL, (3) IMPLICATIONS FOR THE OVERALL PROJECT, AND (4) THE VALUE OF SYSTEMS ANALYSIS AND COMPUTER SIMULATION IN THE STUDY. CHARTS AND TABLES WERE INCLUDED. RELATED REPORTS ARE ED 010 574 AND ED 010 575. (RS)

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System Development Corporation/2500 Colorado Ave./Santa Monica, California 90406

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AUTHOR Jack E. Bratten
TECHNICAL
RELEASE Harry F. Silberman
for Jules I. Schwartz
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The Organization of Interrelated Individual Progress and Ability Level Courses in Mathematics at Garber High School: System Analysis and Simulation

ABSTRACT

This Tech Memo is the third in a series of three reporting the work done at Garber High School in connection with the study New Solutions to Implementing Instructional Media Through Analysis and Simulation of School Organization. A model of the mathematics department at Garber as a system for processing students is described, and a study is reported of the results obtained through simulating this system on a computer.

* * * * * *

I. INTRODUCTION

This year the mathematics department at Garber High School, located in Essexville, Michigan, is beginning a program of interrelated courses that are organized to accommodate a wide range of student needs. SDC document TM-1493/161/00, dated 27 January 1966, describes the program plan in detail. Full utilization of the plan must wait until the present first-year students* have been exposed to the possibilities offered during the six years they will be in the school.

*Garber High School is a combined junior-senior high school. First-year students are those who have entered the school from the elementary level.

An outstanding feature of the plan is its flexibility in providing a unique program of courses to meet the varied abilities and interests of individual students in the Garber student body. To this end, some of the courses are parallel versions of others, differing only in the level of student ability they are designed to accommodate. In addition, many courses are flexible in the length of time that students can spend in completing them. Because of the great number of options that are available to students or that result from their performance, it is possible to provide a great variety of individual programs in mathematics.

The present document has four purposes. The first is to describe a model of the courses in the Garber mathematics department as a system for processing students. The model shows the complex interrelationships among the 29 courses offered by the department and the multitude of optional pathways along which students may proceed as they receive their education in mathematics. The second purpose of this document is to report the results obtained in an exploratory study using a computer to simulate the behavior of students as they are processed by this system and to predict the use that will be made of the various courses when the department is fully operational six years from now. The third purpose is to draw implications from the results of this specific study as they relate to the objectives of the over-all project of which it is a part. The fourth purpose is to discuss the value of system analysis and computer simulation in the present study.

II. TECHNICAL DISCUSSION

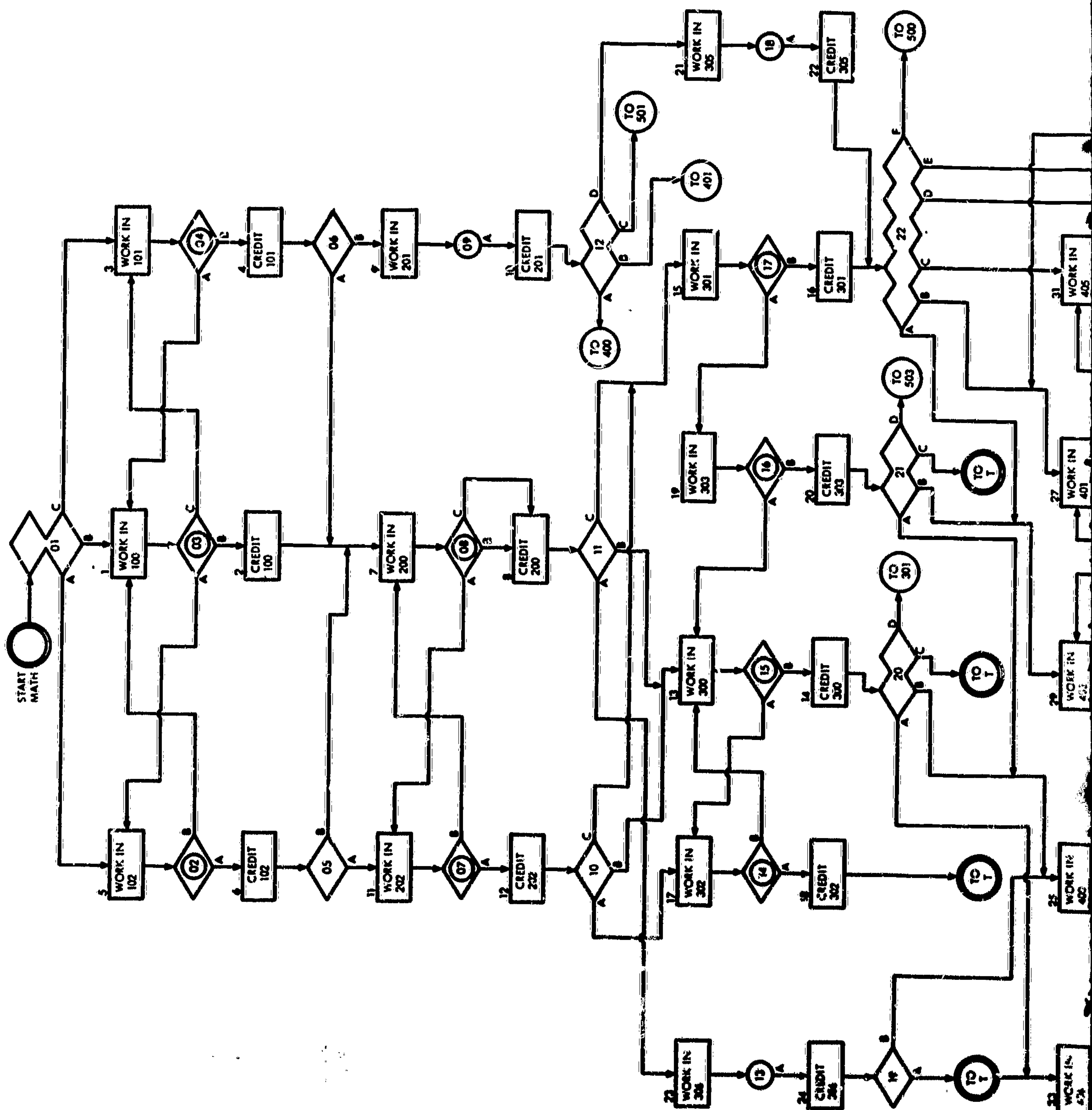
A. THE MATHEMATICS DEPARTMENT AS A SYSTEM FOR PROCESSING STUDENTS

Figure 1 is a diagram of the mathematics department at Garber High School, viewed as a system for processing students. Data for this figure came from the description of mathematics courses presented in the school's Curriculum Guide.*

Figure 1 shows the possible pathways that students may take as they move from one course to another. These pathways are represented by the arrows that connect the courses. For example, a student may work in Math 100 (represented in Figure 1 by the rectangle in the top center position). While working in this course, three things can happen to him; these are shown by three arrows leading from the diamond symbol. He can complete the course and be credited with Math 100, or he can switch either to Math 102, or to Math 101.**

*An excerpt from the guide is presented as Appendix A in SDC document TM-1493/161/00.

**A table giving a short description of the 29 mathematics courses appears in Appendix A.



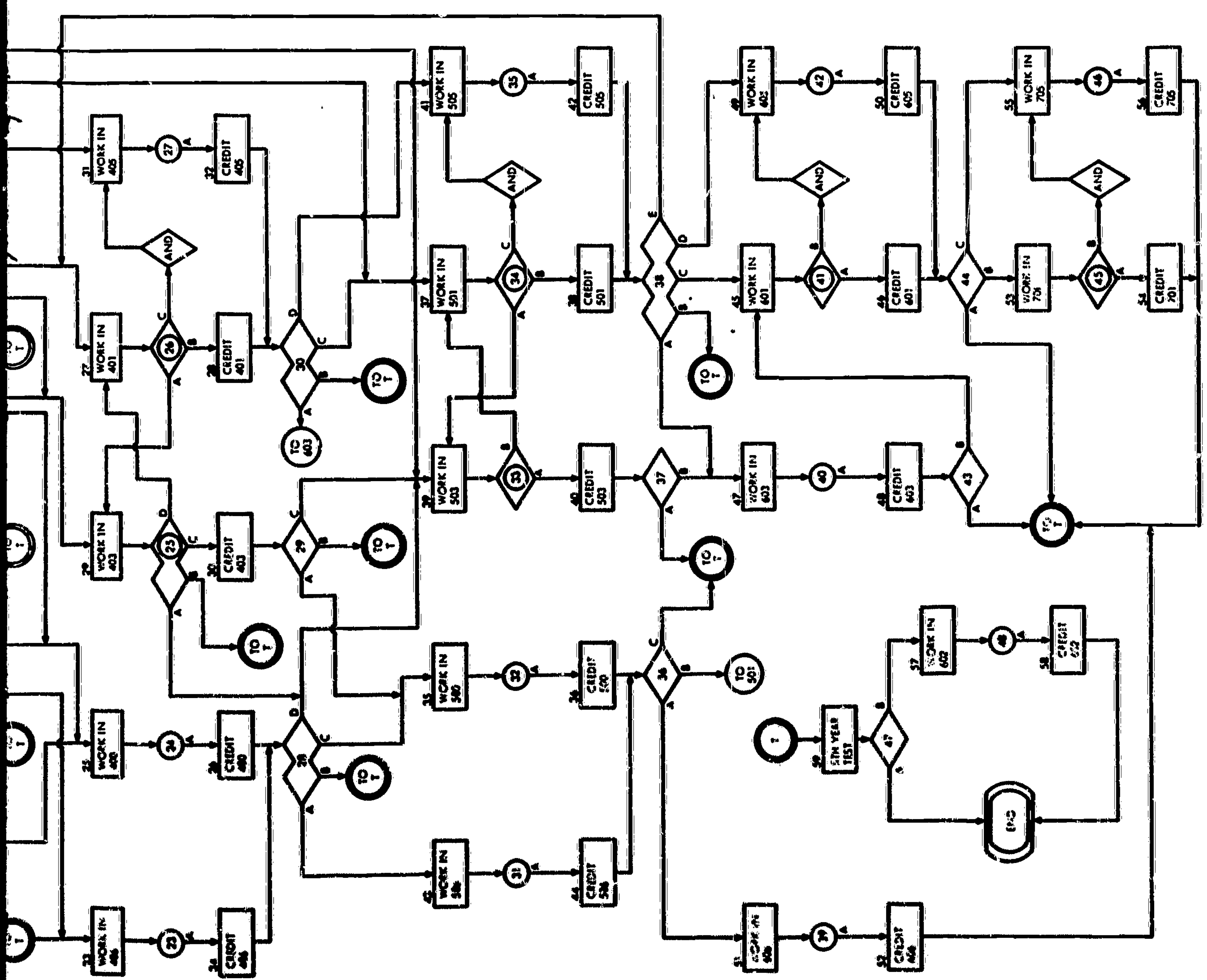


Figure 1. Diagram of System for Processing Students through Courses in Mathematics at Garber High School.

The diamond symbols represent locations in the system where decisions are made about where a student will be at his next location. Some of these decision points are within a course, such as in the above example. This kind of point represents a question about the appropriateness of the course for the student and provides a path so he can be shifted to another course. Other decision points indicate a choice that occurs after completion of a particular course. For example, the diamond symbol that follows the box representing credit in Math 200 indicates that at this point a student may elect Math 306, Math 300, or Math 301. Using Figure 1, it is possible to trace all of the possible pathways that a student might take through the mathematics courses at Garber.* The vertically oriented diamond that connects "Work in 401" with "Work in 405" indicates that these two courses may be taken simultaneously. The same is true for 501 and 505, 601 and 605, and 701 and 705.

After a student is credited with a "300" series course, it is possible for him to stop taking any more mathematics courses. This is shown on the chart as a location symbolized by a double circle surrounding the letter "T." Actual completion of the mathematics requirements, however, is contingent on passing a mathematics abilities test given to all students in their fifth year. If this test is not passed, the student is required to take Math 602 in his sixth year. Thus a student may go to location T from Math 302 in his fourth year at Garber, but he is not finished with mathematics until he takes and passes the test given in his fifth year. The relationships among Math 602, the fifth-year test and the end of work in mathematics is shown in Figure 1 in the lower lefthand corner as a short loop beginning with "T" and leading to "End."

The system representing the possible pathways that students may take through mathematics is more complex when time is considered as a variable. Many of the courses illustrated in Figure 1 can be completed by students in variable lengths of time. This is illustrated in the chart by the single small circle which at times is combined with a diamond to indicate multiple possibilities. Looking at Math 200, for example, the population of students working in that course may have any of the following possibilities occur to them: some may be transferred to Math 202 at day 60 in the course; others may complete Math 200 and begin Math 301 at day 90; while others may complete Math 200 at day 180 and elect to take Math 301, Math 300, Math 306, or go to "T." Appearance of the circle without a diamond indicates that time alone may vary. For example, the circle appearing after the box labeled "Work in 306," symbolizes the possibility that a student may spend either 90 or 180 days in that particular course.

*The numbers and letters that appear with the diamonds and circles are explained later in connection with modeling the system for simulation.

B. MODELING THE SYSTEM FOR SIMULATION

SDC document TM-1493/314/00, dated 22 March 1965, describes a computer simulation capability for educational systems that was used to simulate the progress of students through the Garber High School mathematics curriculum. In brief, this capability consists of a set of programs in the JOVIAL programming language for the Philco 2000 computer. The programs are modular in form so that a model of an educational system, such as the Garber mathematics curriculum, can be constructed by selecting and combining a subset of existing modules into a new configuration.

Use of the simulation capability requires that the modeler define his system by activities and rules that are used by the system to process students. In the case of the present system, activities are defined as working in the various courses and receiving credit for them. The two activities, working and getting credit, are associated with each of the 29 courses, making a total of 58 activities which are symbolized in Figure 1 by the rectangles.

One of the three sets of rules governing the processing of students by the system pertains to branching paths or the sequencing of activities. These rules are represented by the arrows in Figure 1, and were described in Section II A. The second set of rules controlling the progress of students pertains to the length of time that they will spend in the 29 "work" activities. The third set of rules refers to the criteria for branching students at each of the choice points. Data from which the last two sets of rules were derived were obtained from estimates made by the chairman of the mathematics department at Garber High School. The latter points are symbolized by diamonds in Figure 1 and their function is explained in Section II A above. The second and third sets of rules are made explicit by the table in Appendix A, which may be explained by relating it to Figure 1.

The left-hand column in the table in Appendix B contains the numbers of the 48 control points that also appear in Figure 1 within the circles, diamonds, and combined circles and diamonds. Each control point affects either the time that a student will spend in a work activity, or the way he will exit from an activity, or both. For example, in Appendix B, the data appearing in the second column from the left and associated with control point 02 on the table show that a student may exit from the activity controlled by point 02 on day 30, 60, 90, or 180. Figure 1 indicates that this activity is labeled "Work in 102." The third column on the table lists the percentage of the student population in the activity that will exit from that activity on each of the days. Thus 5% will exit on day 30, 5% on day 60, 5% on day 90, and the remaining 85% on day 180. The students who leave Math 102 distribute themselves according to when they leave. The way they will distribute is shown by the section of columns labeled "Distribution by Exit." The letters appearing under this heading on the table are associated with the letters identifying the exits from control points as shown in Figure 1. Thus, for the 5% of students who exit from control point 02 on day 30, none will take Exit A and 100% will take Exit B. Exit A, as identified in Figure 1, leads to credit in Math 102 and Exit B leads to work in Math 100.

Some control points (see number 12 in the table) do not require time. These points represent decisions about the next course that a student may take, and hence do not consume course days.

C. THE SIMULATION PROBLEM

The activities and rules for processing students comprise the data that were used to simulate the mathematics curriculum at Garber High School. The problem posed was to process simulated students through the model to determine the demands that would appear for the various courses. The model represents a six-year plan which is currently in its first year of operation. It is of great practical interest to Garber High School to be able to anticipate how students will distribute themselves into the 29 mathematics courses when the plan has been in operation for six years.

The procedure used in the present simulation study was to generate 100 simulated students who distribute themselves at control point 01 into Math 102, 100, and 101 according to the distribution rule in Appendix B. These students are processed by the simulator for 180 simulated days (one school year). During this time some students will switch from Math 102 to Math 100; from Math 100 to Math 102 and Math 101; and from Math 101 to Math 100, according to the distribution rules. On day 180, all the remaining students will complete the course they are working in and will be moved to the next control point for distribution to a new course. On day 181, another population of 100 students will be processed through control point 01 to follow the first group. On simulated days 361, 541, 721, and 901, four more groups of 100 students each will enter the system at control point 01. At the end of 1,080 simulated days, the first group of 100 students will have been processed completely through the model and each of the other five groups will have completed a simulated 5, 4, 3, 2, or 1 year study in mathematics. At this point in simulated time, each activity in the model will have had an opportunity to be utilized.

D. RESULTS OF SIMULATION

The product of simulation is a data tape on which is recorded each decision made about a student with reference to specific activities and time. In addition, each student carries an identity of high, middle, or low aptitude, and the year that he began mathematics. Use of this data tape in connection with data reduction programs makes it possible to produce a number of different listings that can be used to answer specific questions. For example, it is possible to produce a history for a specified student that shows which courses he took, which courses he received credit for taking, and the amount of time spent in each course.

The first information taken from the data tape was a history of what had happened over the six simulated years to each of a sample of ten simulated students. This sample was stratified to include two low-, six middle-, and two high-aptitude

students; the specific students were randomly selected by the computer. The programs produced by the model for the ten simulated students are presented in Table 1. In this table, each student is identified by a number appearing in the first column on the left. The next column shows the aptitude in mathematics assumed for the particular student, and the third column lists the courses assigned to him by the simulation. The next six columns contain a time line that shows how much time he spends in each course. The figures on this line show the number of days spent in each course. The student does not receive credit for some courses because he was changed to another course more appropriate to his ability. These courses are starred in column three.

In order to further explain Table 1, one of the student programs produced by the computer can be examined and related to possible real events that occur in the mathematics department at Garber. Student 101, for example, was assigned to Math 102 on the basis of his previous performance in mathematics. He took Math 102 during his first year, Math 200 during the second, and Math 300 during the third. At this point he stopped taking mathematics. When he was in his fifth year at Garber, he took the school-wide mathematics abilities examination given to fifth-year students and failed to pass it. As a consequence, he was required to take Math 602 during his last year in the school. The other programs in Table 1 can be interpreted similarly.

Of primary interest to this study are data that bear on two questions. The first has to do with the predicted enrollment in each course at the end of the 1970-71 school year. Table 2 presents these data and is described below. The second question asks what will be the use made of each course during the six years extending from the present school year, 1965-66, to the school year 1970-71. Table 3 shows this prediction and will be described later.

The data in Table 2 were produced by computer simulation of a model of the mathematics curriculum as described in Sections A, B, and C, above. The first column on the left of Table 2 lists the courses in the mathematics department. The row labeled "Term Math" shows the number of students who terminated work in mathematics prior to June 1971. Termination means that they were in school but not enrolled in a mathematics course. The bottom row shows the total number of students in school as of June 1971. This enrollment figure was obtained by taking the current size of the first-year class (124 students) and postulating an approximate 10% annual increase in subsequent first-year groups. School officials estimate that the size of Garber's enrollment in five years will be about 900 students.

Several results shown by Table 2 are worth noting for later discussion. The predicted June 1971 enrollment appearing in the second column from the left shows enrollment figures ranging from zero (for Math 305, 306, 406, 605, 606, and 705) to 114 for Math 100. There are five courses (Math 302, 405, 505, 506, and 602) with enrollments of less than ten students. Of the total enrollment of 962 students, 217, or 23%, are not taking a course in mathematics. Comparison between the total enrollment and the number of students not taking mathematics

Table 1. Sample Programs in Mathematics Produced by Simulation

Stud.	Apti-tude	Courses	Days Spent in Each Course					
			First Year	Second Year	Third Year	Fourth Year	Fifth Year	Sixth Year
101	Low	102	180					
		200		180				
		300			180			
		Test					Failed	
		602						180 →
107	Low	102	180					
		200		90				
		301			180			
		503				180 →		
		Test					Passed	
108	Mid	100	180					
		200		90				
		301*		90				
		303			180			
		503				180		
		Test					Passed	
109	Mid	100	180					
		200		180				
		301			180			
		401				180		
		501					180	
		Test					Passed	
115	Mid	100	180					
		200		90				
		301			180			
		501				180		
		Test					Passed	

*Indicates that credit was not given for this course.

Table 1. Sample Programs in Mathematics Produced by Simulation (Continued)

Stud.	Aptitude	Courses	Days Spent in Each Course: First Year	Second Year	Third Year	Fourth Year	Fifth Year	Sixth Year
118	Mid	100*	90					
		102	90					
		202		180				
		200			180			
		301				180		
		403					180	
		Test					Passed	
		603						180
119	Mid	100	180					
		200		180				
		301*			60			
		303*			90			
		300				180		
		Test					Passed	
203	High	101	180					
		201		135				
		401			225			
		603				180		
		601					180	
		701						180
		Test					Passed	
204	Mid	100	180					
		200		180				
		301*			90			
		303				180		
		503					180	
		Test					Passed	

*Indicates that credit was not given for this course.

Table 1. Sample Programs in Mathematics Produced by Simulation (Continued)

Stud.	Apti-tude	Courses	Days Spent in Each Course					
			First Year	Second Year	Third Year	Fourth Year	Fifth Year	Sixth Year
207	High	101	180					
		201		135				
		401			225			
		501				180		
		601					135	
		701						180
		Test					Passed	

Table 2. Predicted Enrollment by Course

Course No.	June 1971 Enrollment	Enrollment Distribution by Student Level					
		Sixth Year	Fifth Year	Fourth Year	Third Year	Second Year	First Year
100	114						114
101	42						42
102	44						44
200	103				02	101	
201	55					55	
202	30				03	27	
300	11				11		
301	36			03	33		
302	02				02		
303	11			01	10		
305	--						
306	--						
400	11	01		03	07		
401	51	07	07	21	16		
403	32	05	06	10	11		
405	02				02		
406	--						
500	15		04	03	08		
501	64	03	14	23	24		
503	21	01	07	05	08		
505	06		03	01	02		
506	02		01	01			
601	37	05	10	17	05		
602	09	01	03		05		
603	26	08	02	13	03		
605	--						
606	--						
701	21	09	04	08			
705	---						
Term. Math	217	84	76	42	15		
Total Enroll-ment	962	124	137	151	167	183	200

for each level shows that 68% of the sixth-year, 55% of the fifth-year, 28% of the fourth-year, and 9% of the third-year students are not in mathematics. All students in the first- and second-year groups are enrolled in a mathematics course. In almost every instance where a course above the "300" series has an enrollment of over ten, the class is made up of students from the third, fourth, fifth, and sixth years. The exceptions are Math 400, 500, and 701 which contain students from three levels. This latter result obtained by simulation vividly illustrates Garber's desire to have "nongraded" classes (see TM-1493/160/00, dated 4 January 1966, for a detailed discussion of Garber's objectives).

Table 3 shows the number of students that simulation of the model predicts will receive credit for the different courses between September 1965 and June 1971. The students working in courses as of June 1971 are shown in Table 2 but are not included in Table 3. The number of people receiving course credit is shown by year. Examination of Table 2 shows that Math 100 was credited to a total of 387 students during the simulated time. Seventy-one of the present (June 1971) sixth-year, 78 fifth-year, 74 fourth-year, 81 third-year, and 83 second-year students received credit in this course. Since no first-year students had earned credit by this date, they do not appear on the table. Comparable data are shown for the other courses. Limited or no usage is predicted for the '05 and '06 courses in all series (305, 306, 405, etc.). The major patterns of usage run through the '00 sequence (100, 200, 300, etc.), the '01 sequence (101, 201, 301, etc.), and the '03 sequence (303, 403, 503, etc.).

Table 4 presents the results of comparing the predicted enrollment by course for late June 1971 with the predicted enrollment for the same courses three simulated weeks earlier. The second column shows how the total school enrollment of 962 students was distributed by course in early June; the third column shows how the same number of students were distributed three simulated weeks later. The column labeled "Gain" shows increases and the column labeled "Loss" shows decreases in the size of each course during the three-week period. The largest difference is in the "Term" category indicating that 17 additional students had ceased taking any course in mathematics during this period. Differences may be seen in about one-half the courses; the largest increase was in Math 301, where the enrollment increased by nine. The differences do not represent the total number of changes made by the students as individuals because they are based on total enrollment. For example, the loss of four students in Math 300 may represent the addition of two new students and the loss of six to the course. Therefore the difference in enrollment represents the minimum number of student transactions (transfers in or out of the course) that could have occurred. There may have been some unknown number of new students added to the course, but it is known that at least four students were transferred out of the course. Thus the total number of student transactions occurring during this time period was at least 88 (the sum of all gains and losses). The implications of this result are discussed below.

Table 3. Predicted Use of Courses Between September 1965 and June 1971*

Course Number	Total Students Receiving Credit	Course Credit Received by Student Level				
		Sixth Year	Fifth Year	Fourth Year	Third Year	Second Year
100	387	71	78	74	81	83
101	208	30	39	47	43	49
102	175	30	22	30	42	51
200	398	96	92	95	115	
201	152	29	39	47	37	
202	34	07	08	09	10	
300	85	25	24	18	18	
301	219	55	53	66	45	
302	14	03	03	05	03	
303	51	18	21	11	01	
305	01	01	--	--	--	
306	04	03	01	--	--	
400	35	13	13	08	01	
401	161	57	50	36	18	
403	10	05	01	01	03	
405	01	--	--	01	--	
406	03	--	03	--	--	
500	16	08	06	02	--	
501	161	53	50	48	10	
503	48	22	15	11	--	
505	--	--	--	--	--	
506	01	01	--	--	--	
601	53	26	15	12	--	
602	15	12	03	--	--	
603	60	34	18	08	--	
605	02	01	01	--	--	
606	--	--	--	--	--	
701	11	07	04	--	--	
705	--	--	--	--	--	

*Note: Table 3 and Table 2 are independent. To obtain predicted use of courses assuming that students shown in Table 2 will receive credit, the two tables may be summed.

Table 4. Changes in Course Enrollment During Last Three Simulated Weeks

Course Number	Early June Enrollment	Late June Enrollment	Gain	Loss
100	114	114		
101	42	42		
102	44	44		
200	103	103		
201	55	55		
202	30	30		
300	15	11		04
301	27	36	09	
302	04	02		02
303	22	11		11
305	--	--		
306	--	--		
400	18	11		07
401	57	51		06
403	25	32	07	
405	--	02	02	
406	--	--		
500	15	15		
501	64	64		
503	28	21		07
505	03	06	03	
506	--	02	02	
601	40	37		03
602	13	09		04
603	26	26		
605	--	--		
606	--	--		
701	17	21	04	
705	--	--		
Term.	200	217	17	
Totals	962	962	44	44

III. IMPLICATIONS OF RESULTS FOR THE PROJECT "NEW SOLUTIONS"

Of major interest in discussing the results of this study are the implications to the over-all objectives of the project New Solutions to Implementing Instructional Media Through Analysis and Simulation of School Organization. Briefly these objectives are to:

- define new roles for school personnel;
- provide information on the effects of new media;
- describe new applications for data processing;
- provide information on amount and arrangement of space; and
- provide estimates of characteristics of students graduating from the schools.

A. DEFINITION OF NEW ROLES FOR PERSONNEL

An analysis of the simulation results can be used to specify some personnel requirements that must be met by the mathematics department when the Garber plan is fully operational. According to the predicted enrollment, there will be 745 students taking mathematics in 23 different courses. Limiting enrollment in a particular class to about 25 students and leaving out the three independent study courses, approximately 33 classrooms of students will result from the predicted enrollment. If a teacher spends five hours a day in classrooms and students take four hours of instruction per week in a single course, about six instructors are required to handle the predicted load. These estimates are in line with the present situation where five instructors serve 588 students.

The tasks of an instructor in a classroom that is fully operational under this plan can best be visualized by considering some of the simulated data as related to procedures. A course such as Math 401 never begins or ends from the instructors' viewpoint; it operates continuously. Students are coming into the course and leaving it in small groups of from two to ten students every 45 days. Since students may finish the course in 135, 180, or 225 days, and may enter every 45 days, there is a probability that some students will be working at any given point in the course content sequence on any specific day. This implies that an instructor must be equipped to help students with any part of the full range of content in a course, on any day it is operating.

Moreover, the data from simulation show that Math 401 (and most courses above the 200 level) will contain students ranging in chronological age from early to late teens. Instructors must be prepared to deal with the differences in students that may be due to age. For example, the task of helping a student define his learning problems and select a course of action may be different for a freshman

than for a senior simply because one is taking the course as a result of a genuine interest in mathematics and the other needs it in order to get into a college he plans to attend.

Individualized instruction implies a drastic redefinition of the conventional instructor's role. The movement of students in and out of courses in the way suggested by the Garber data is possible only because the responsibility for presenting content has been shifted from an instructor lecturing before a group of students to media that can be used in an individual mode. The instructor's role, thus, shifts from that of a presenter of content in a group mode to that of a consultant who can work with an individual student to help him define the problems he is having with self-instructional materials and advise him on the selection of a course of action that will solve his learning problems. In any given day at Garber the instructor may be consulting with students of many ages over a wide range of content material, so his appreciation for the range of educational needs of students and his ability to work over a wide range of mathematical concepts are necessary requirements.

The role of student in a school using individualized instruction changes when compared to a conventional school. The student must make many decisions that are made for him in the traditional classroom. For example, he decides when he is ready to be tested and, in general, is permitted to select his specific day-to-day activities. Schools that take the individualized approach are committed to an assumption that students can successfully make such decisions. Therefore, it is not surprising that these schools report student success in this regard.

One of the strongest arguments against individualization is a conviction on the part of some administrators that their student body is not capable of the kind of responsibility required in order to individualize instruction. For this reason it is important that the reported success of Garber's students in managing their own instruction be somehow defined and demonstrated. The present study has focused on the mathematics department as a total system; therefore, no data bearing on this specific question has been produced. This problem requires further research.

The department chairman has been the major individual concerned with the production of materials (study guides, tests, etc.), selection of media (texts, etc.), and the formulation of procedures for organizing instruction within the department. This role is extremely important in giving the department its unified and coordinated characteristics. This job also entails defining the instructors' role and organizing the training needed to integrate those individuals into the system.

In addition, the role of the school counselor as it interfaces with the mathematics department at Garber is being redefined. In a traditional school, courses usually are selected by the student in conjunction with the counselor. A department is usually only concerned with whether or not a student has met specific

prerequisites. At Garber, the mathematics department is very much concerned about the individual needs of students in its area of study. As a consequence, an annual planning conference is held with each student to plan the next year's program of study in mathematics. This conference limits the decisions that can be made in counseling, since the department has already decided with the student whether or not he will take mathematics and the specific course he will take.

B. EFFECTS OF NEW MEDIA ON STUDENTS

Study guides and mastery tests are used to a great extent in the mathematics department. A study guide tells students on a day-to-day basis what they must do to accomplish the objectives of a course. It is written so that a student can begin a course at any time, and it leads him step-by-step through the course. For any given concept or unit, the guide may direct a student to various media for instruction. He may, for example, be directed to read sections from one or more texts, work some exercises, view a filmstrip, listen to an audio tape, consult with an instructor on a specific point, etc., all in connection with the same unit of study. Mastery tests determine whether or not a student has achieved mastery of the unit objectives or not.

The present study has not produced specific data on the effects of media on student-student or student-teacher interaction. Full implementation of the Garber plan does have implications for this area of interest, however, and this is related to the use of study guides. To the extent that student-student interaction is deemed to be one of the objectives of a unit of study, this can be provided for in the guide by scheduling small group discussions. The study guide in Math 301 used at Garber contains such provisions. Virtually every one of the 11 concepts included in this guide has a requirement that the student get together with a few others working on the same concept to discuss specific topics. In addition, the student using the guide is often reminded to ask the instructor for clarification about specific points. As a result, student-student and student-teacher interaction is planned in order to attain specific objectives. Moreover, the freedom from a single medium of instruction provided by study guides enables the course designer to achieve his goals in a variety of ways.

C. NEW APPLICATIONS FOR DATA PROCESSING

The Garber plan assumes that when a student finishes an individualized course he can immediately begin the next one. Therefore, most students will be receiving credit for one course and beginning the next one in a sequence at times that does not coincide with the end of a term (quarter, semester, school year, etc.). Other students will be switching from one version of a course to another, not at specific divisions of the calendar, but when it is appropriate for them, based on their progress. The frequency of transfers from one course to another within the mathematics department was estimated in the present study and presented

above in connection with Table 4. These results show that when the plan is in full operation, at least 88 such transactions will occur during a period of 15 school days. Of the 745 students enrolled in courses in the spring of 1971, approximately 12% will move from one course to another during three school weeks. In addition, when all courses in mathematics are individualized, there will be a need to administer about 10,000 tests a year in the department. (This figure assumes ten concepts in each course with 75% of the 745 students taking one test for each concept and about 25% taking two for each concept. An average of about 55 test administrations will occur daily.

The task of record keeping--of knowing the whereabouts of each student in terms of his progress in his present course and where and when he is to move to another--requires a sophisticated approach to information processing. The handling of 745 individual records involving a half-dozen transfers and the posting of some 55 test grades daily is a major bookkeeping task. Add to it the job of evaluating and scoring tests and the resulting workload could require several full-time clerks.

Project personnel, in connection with their study of two other high schools attempting to individualize instruction, have observed this general problem in those contexts.* A general solution was proposed in SDC documents TM-1493/103/00 dated 28 February 1964, and TM-1493/104/00 dated 13 March 1964. Project personnel propose an information processing system using modern data processing technology to (1) predict the expected behavior of students; (2) to record their day-to-day progress; and (3) to present to instructors, principals, counselors, students, etc., displays of information to assist them in analyzing decisions about appropriate actions. The system would also score tests and maintain an up-to-the-minute cumulative record on each student.

D. INFORMATION ON AMOUNT AND ARRANGEMENT OF SPACE

The four functions in the mathematics department at Garber High School that appear to require different space allotments are (1) space for individual study; (2) space for testing; (3) space for student-teacher consultation; and (4) space for small group discussions. Predicted data from this study indicate that the present Garber High School procedure of having students study in regular classrooms with an instructor present to give assistance when it is needed will require about 33 classrooms if the students meet daily. If they meet on Monday, Wednesday, and Friday in some classes and Tuesday and Thursday in others, the daily demand can be cut in half. The present flexibility at Garber High School to adjust the size of classrooms with folding partitions appears to anticipate the variety of class sizes predicted in the simulation study.

*The two schools are Brigham Young University Laboratory School, Provo, Utah, described in SDC document TM-1493/103/00, dated 28 February 1964, and Theodore High School, Theodore, Alabama, described in SDC document TM-1493/110/00, dated 7 December 1965.

The need to give an average of 55 tests daily, predicted in this study, indicates that the present facility accommodating 25 students simultaneously, may be sufficient if the load is distributed fairly evenly.

Student-teacher consultations are presently held either in the classroom while other students are studying or in the general teachers' office. In both cases, space is serving more than the function of consultation which tends to demean the importance of this effort. In discussing the instructors' role above, the point was made that the task of consulting will be the major function of the instructors in the fully operating Garber plan. It appears to the authors that as the function of consultation becomes more clearly defined by both instructors and students, more emphasis will be put on this function. This in turn will lead to a need for allocating specific space for the activity. The present study has not produced data that bears on the question of the amount of consulting that will be necessary.

E. ESTIMATION OF THE CHARACTERISTICS OF GRADUATING STUDENTS

The present study predicts that the students graduating from Garber in June, 1971, will have earned a total of 607 course credits in mathematics in 24 different courses. This represents an average of 4.9 courses per student. About 32% of the class of 1971 will be enrolled in mathematics courses when their high school careers end. One important unanswered problem that must be solved by Garber officials is to determine what can be done with students who are in various stages of progress in courses when they graduate. One possibility is that the courses can be finished during the summer.

IV. CONCLUSIONS ABOUT THE USE OF SYSTEM ANALYSIS AND COMPUTER SIMULATION TECHNIQUES IN THIS STUDY

Since a major purpose of this study has been to explore the uses of system analysis and simulation techniques in studying school organization, some conclusions about the techniques are relevant. The data produced by the simulation described above must be regarded merely as suggestive in the sense that they were produced by the initial version of a model. Before confidence can be placed in the data, successive cycles involving careful critical analysis of the results and preparation of new versions of the model should occur. For example, a careful study of many student programs produced by the model (illustrated in Table 1) could be conducted to assess their reasonableness. The question as to whether the model is simulating "reality" may be answered in part by asking whether the student programs that it produces are sufficiently "real" that one is willing to substitute the model for the students' behavior in terms of the summary data that it produces. The user of the model must make this judgment, for it is he who must have confidence in its performance.

The virtues claimed for the techniques of system analysis and computer simulation as used in this study are as follows: (1) simulation has forced a formulation of the prediction problem in the mathematics department so that it can be systematically approached; (2) this formulation puts the prediction problem in a form that can be rapidly solved by a computer; and (3) the results of simulation--the data which it yields--are useful in the formation of hypotheses about ways that the system can be improved. An example of this is presented below.

The over-all objective of the Garber plan is to provide a curriculum that will serve the individual needs of students with respect to their interests and abilities in mathematics. The implication is that a plan meeting this objective will provide courses with sufficient appeal to students that they will continue working in mathematics beyond the years when the subject is a requirement. The results of simulation predict that 68% of the sixth-, 55% of the fifth-, and 28% of the fourth-year students will not take mathematics. Of all students in these three upper levels, approximately one-third will not be enrolled in a mathematics course.

If Garber officials are concerned with this dropout rate in mathematics and interested in a remedy, they might start by identifying those courses with low frequency of usage (the '05 and '06 courses in Table 3, for example) and then examine the channels that feed them (Figure 1). For example, Math 606, which is an independent study course in applied mathematics for sixth-year students, has no predicted usage between now and 1971. An examination of Figure 1 shows that it is available only to students who have completed Math 506, a similar course for fifth-year students, and Math 500, an advanced course in technical mathematics. Study of Figure 1 shows clearly the alternatives that are available for increasing the usage of 606. For example, eliminating Math 501, a geometry course, as an alternative choice for students who complete advanced technical mathematics (500), would effect 606 as well as 501.

While the analysis does not automatically provide answers, it can be used as an aid in generating hypotheses about more effective procedures. Before solutions are actually implemented in the school, it is recommended that further simulation studies of the modified system incorporating the hypothetical procedures be conducted.

APPENDIX A

Tables Showing Distribution Rules that Govern Time and Branching

APPENDIX A (Cont'd.)

Control Point	Exit on Day	Percent of Population	Distribution by Exit (%) A	B	C	D	E	F
01	00	100	20	55	25			
02	30 60 90 180	05 05 05 85	00 00 00 100	100 100 100 00				
03	60 90 180	05 12 83	100 42 00	00 00 100	00 58 00			
04	60 90 180	05 05 90	100 100 00	00 00 100				
05	00 00	05 95	00 100	100 00				
06	00 00	05 95	100 00	00 100				
07	60 90 180	05 10 85	100 100 00	00 00 100				
08	60 90 180	05 33 62	100 00 00	00 100 100				
09	135 180	10 90	100 100					
10	00 00 00	30 60 10	100 00 00	00 100 00	00 00 100			
11	00 00 00	01 25 74	100 00 00	00 100 00	00 00 100			

APPENDIX A (Cont'd.)

Control Point	Exit on Day	Percent of Population	Distribution by Exit (%) A	B	C	D	E	F
12	00	02	100	00	00	00		
	00	60	00	100	00	00		
	00	37	00	00	100	00		
	00	01	00	00	00	100		
13	180	100	100					
14	90	20	00	100				
	180	80	100	00				
15	90	10	100	00				
	180	90	00	100				
16	90	25	100	00				
	180	60	00	100				
	270	15	00	100				
17	90	25	100	00				
	135	15	00	100				
	180	45	00	100				
	225	15	00	100				
18	90	50	100					
	180	50	100					
19	00	80	100	00				
	00	20	00	100				
20	00	02	100	00	00	00		
	00	40	00	100	00	00		
	00	48	00	00	100	00		
	00	10	00	00	00	100		
21	00	20	100	00	00	00		
	00	25	00	100	00	00		
	00	30	00	00	100	00		
	00	25	00	00	00	100		
22	00	20	100	00	00	00	00	00
	00	30	00	100	00	00	00	00
	00	01	00	00	100	00	00	00
	00	30	00	00	00	100	00	00
	00	14	00	00	00	00	100	00
	00	05	00	00	00	00	00	100

APPENDIX A (Cont'd.)

Control Point	Exit on Day	Percent of Population	Distribution by Exit (%)					
			A	B	C	D	E	F
23	90 180	50 50	100 100					
24	180	100	100					
25	30 60 90 135 180 270	02 03 05 05 68 17	50 50 00 00 00 00	50 50 00 00 00 00	00 00 00 00 100 100	00 00 100 100 00 00		
26	00 90 135 180 225	 20 16 48 16	00 100 00 00 00	00 00 100 100 100	100 00 00 00 00			
27	90 180	50 50	100 100					
28	00 00 00 00	03 45 47 05	100 00 00 00	00 100 00 00	00 00 100 00	00 00 00 100		
29	00 00 00	15 05 80	100 00 00	00 100 00	00 00 100	00 00 00		
30	00 00 00 00	23 05 70 02	100 00 00 00	00 100 00 00	00 00 100 00	00 00 00 100		
31	90 180	50 50	100 100					
32	180	100	100					
33	90 180 270	10 72 18	00 100 100	100 00 00				

APPENDIX A (Cont'd.)

Control Point	Exit on Day	Percent of Population	Distribution by Exit (%) A	B	C	D	E	F
34	00 90 135 180 225	 10 18 54 18	00 100 00 00 00	00 00 100 100 100	100 00 00 00 00			
35	90 180	50 50	100 100					
36	00 00 00	02 08 90	100 00 00	00 100 00	00 00 100			
37	00 00	30 70	100 00	00 100				
38	00 00 00 00 00	15 30 33 02 20	100 00 00 00 00	00 100 00 00 00	00 00 100 00 00	00 00 00 100 00	00 00 00 00 100	
39	90 180	50 50	100 100					
40	90 180	50 50	100 100					
41	00 135 180	 10 90	00 100 100	100 00 00				
42	90 180	50 50	100 100					
43	00 00	50 50	100 00	00 100				
44	00 00 00	50 49 01	100 00 00	00 100 00	00 00 100			
45	180 00	100	100 00	00 100				

APPENDIX A (Cont'd.)

Control Point	Exit on Day	Percent of Population	Distribution by Exit (%)					
			A	B	C	D	E	F
46	90 180	50 50	100 100					
47	00 00	92 08	100 00	00 100				
48	90 180	50 50	100 100					